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NASA GLOBAL ATMOSPHERIC SAMPLING PROGRAM (GASP)  
DATA REPORT FOR TAPE VL0004

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16. Abstract <p>The NASA Global Atmospheric Sampling Program (GASP) is obtaining measurements of atmospheric trace constituents in the upper troposphere and lower stratosphere using fully automated air sampling systems on board several commercial B-747 aircraft in routine airline service. Atmospheric ozone, water vapor, and related flight and meteorological data were obtained during 139 flights of a United Airlines B-747 and a Pan American World Airways B-747 from December 1975 through March 1976. In addition, sample bottles were exposed during three flights and analyzed for trichlorofluoromethane, and filter samples were exposed during five flights and analyzed for sulfates, nitrates, and chlorides. These data are now available on GASP tape VL0004 from the National Climatic Center, Asheville, North Carolina. In addition to the GASP data, tropopause pressure fields obtained from NMC archives for the dates of the GASP flights are included on the data tape. Flight routes and dates, instrumentation, data processing procedures, data tape specifications, and selected analyses are discussed in this report.</p>			
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DATA REPORT FOR TAPE VL0004

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SUMMARY

Atmospheric trace constituents in the upper troposphere and lower stratosphere are being measured as part of the NASA Global Atmospheric Sampling Program (GASP), using fully automated air sampling systems on board several commercial B-747 aircraft in routine airline service. Measurements of atmospheric ozone and water vapor, and related meteorological and flight information were obtained during 139 GASP flights from December 26, 1975 through March 25, 1976. Also, bottle samples were obtained during three flights and filters were exposed during five flights. These were analyzed respectively for trichlorofluoromethane and sulfates, nitrates, and chlorides. These data are now available from the National Climatic Center, Asheville, North Carolina. In addition to the data from the aircraft, tropopause pressure data obtained from the National Meteorological Center (NMC) archives for the dates of the flights are included. This report is the fourth of a series of reports which describes the data currently available from GASP, including flight routes and dates, instrumentation, data processing procedures, data tape specifications, and selected analyses.

INTRODUCTION

This report announces the availability of atmospheric trace constituent data obtained at altitudes from 6 to 12 km during several flights of a United Airlines B-747 (N4711U) and a Pan American World Airways B-747 (N655PA) from December 1975 - March 1976.

The objectives of the NASA Global Atmospheric Sampling Program are to provide baseline data of selected atmospheric constituents in the upper troposphere and lower stratosphere for the next 5-to-10 year period, and to document and analyze these data to assess potential adverse effects between aircraft exhaust emissions and the natural atmosphere. At present there is much uncertainty in environmental impact studies on this subject due to the lack of comprehensive, long-term upper atmospheric data (refs. 1 and 2).

The GASP program began in 1972 with a feasibility study of the concept of using commercial airliners in routine service to obtain atmospheric data. This program has progressed from design and acquisition of hardware (ref. 3) to collecting global data on a daily basis. Fully automated GASP systems are now operating on a United Airlines B-747, two Pan American World Airways B-747's, and a Qantas Airways of Australia B-747. The United airliner is collecting data over the contiguous United States and between the west coast and Hawaii. Global coverage is provided by the Pan American and Qantas B-747's. Pan Am routes from the United States include around-the-world flights in the Northern Hemisphere, transatlantic flights to Europe, transpacific flights to the Orient, intercontinental flights to Central and South America, and occasionally transpacific flights to Australia. More frequent coverage in the Southern Hemisphere is provided by the Qantas B-747 on transcontinental Australian flights and on flights from Australia to the South Pacific and Australia to Europe. The GASP system design, the measurement instruments, the on-board computer for automatic control and data management, and system maintenance procedures are described in reference 4.

This report is the fourth in a series of reports to announce the availability of GASP data from the National Climatic Center, Asheville, North Carolina, 28801. Northern hemisphere data for March 11 - March 30, 1975 have been previously reported and analyzed (tape VL0001; refs. 5, 6 and 7). Data over the contiguous United States and to Hawaii for March - October, 1975 are provided on GASP tape VL0002 (ref. 8). Data obtained in May 1975 on flights in North, Central, and South America, and from the United States to the Orient are provided on GASP tape VL0003 (ref. 9). Global data for December 26, 1975 through March 25, 1976 are now available on GASP tape VL0004. In addition to the atmospheric constituent measurements, the data on this tape include related meteorological and flight information from the aircraft systems, and tropopause pressure fields obtained from the National Meteorological Center (NMC) for the dates of the GASP flights.

#### ROUTE STRUCTURE AND DATA ACQUISITION

Flight routes for which data are given on GASP tape VL0004 are shown on figure 1. All flights occurred between December 26, 1975 and March 25, 1976. On the tape, GASP data are grouped and identified by flights with the airports of departure and arrival designated by the standard three-letter airport codes (ref. 10). A listing of flights included in tape VL0004 by airport-pair, date, and data acquisition time, is given in table I.

For each flight, data acquisition begins on ascent through the 6 km altitude flight level, and terminates on descent through 6 km. A complete GASP sampling cycle is 60 minutes, divided into 12 five minute segments. A 16 second recording is made at the end of each sampling segment. During alternate segments (at 10 minute intervals), air sample data are recorded for all instruments. During the intervening segments the system is in one of six different calibration modes to allow for in-flight checks on instrument operation (if required). Whenever any calibration mode is not needed for a given instrument, that instrument acquires air sample data during the segment.

Cassette tapes, recorded in serial format, are removed from the aircraft at approximately two week intervals and transcribed to computer-compatible form for data reduction. At this stage, laboratory instrument calibration information required for data processing is included, redundant and non-useable data are removed, and the data are re-transcribed to final form and units. The detailed specifications and formats for the GASP data are given in appendix A. Data for each flight begins with an FLHT record (table A-I) to provide flight identification information. This record is followed by a series of DATA records (table A-II), one for each recording made during the flight.

## MEASUREMENTS

### Ozone

Ozone measurements are made using a continuous ultraviolet absorption ozone photometer (ref. 11). The concentration of atmospheric ozone is determined by measuring the difference in intensity of an ultraviolet light beam which alternately passes through the sample gas and an ozone-free zero gas (generated within the instrument). The range of this instrument is from 3 to 20,000 ppbv (parts per billion by volume), with a sensitivity of 3 ppbv. Data from flight tests of the instrument are given in reference 12. The ozone instrument is checked at NASA-Lewis (over the range 0 to 1000 ppbv) against an ozone generator which is calibrated by the one percent neutral buffered potassium iodide (KI) method (ref. 13). The estimated accuracy of the KI procedure is seven percent.

In-flight monitoring of the ozone instrument includes measurement of the instrument zero by flowing the sample through a charcoal filter external to the instrument, and measurement of the electronic span setting and control frequencies available from the instrument. For all GASP ozone instruments, the span is set by the manufacturer at

58200 counts. The instrument is not calibrated in-flight with an ozone calibration gas due to the difficulty of generating a precisely known ozone concentration in the flight system. Periodic checks for calibration consistency are performed in the laboratory.

The destruction of ozone in the Teflon sample lines from the inlet probe to the instrument, and in the Teflon-coated diaphragm pump that raises the sample pressure to 100 kPa (1 atm), has been measured under conditions simulating operation in flight. The ozone mixing ratio at the probe inlet ( $O_3$ , in ppbv) is expressed in terms of the measured ozone mixing ratio ( $O_{3m}$ , in ppbv) as

$$O_3 = a(O_{3m})^b + \frac{O_{3m}}{1 + c(O_{3m})} + d \quad (1)$$

with the constants  $a$ ,  $b$ ,  $c$  and  $d$  determined by a regression analysis on the appropriate destruction test data. For all flights on tape VL0004, the ambient ozone mixing ratios were determined using equation (1) with  $a = 0.19$ ,  $b = 1.0$  and  $c = d = 0$ . The linear relationship between  $O_3$  and  $O_{3m}$  thus defined, and the data from which it was determined are shown in figure 2. The uncertainty in this approximation is  $\pm 8$  percent. The destruction constants used are given in the FLHT record for each flight (see table A-I).

The form chosen for equation (1) is based on the ozone destruction mechanisms expected in the GASP system. If  $b = 0.5$  in the first term, this term then approximates destruction of ozone in the sample lines (c.f. ref. 14). If  $c > 0$  in the second term, this term is of the type which describes thermal decomposition of ozone (refs. 15 and 16). This mechanism could be important in the pump as the sample is heated by the (approximately) 3:1 compression. The percentage of the incoming ozone destroyed by the line mechanism decreases with increasing concentrations, whereas the percentage of the incoming ozone destroyed by the thermal mechanism increases with increasing concentration. Since both mechanisms are likely contributing to the system destruction, it is not surprising that the destruction data are approximated well with a linear relationship which gives a constant percentage destruction.

#### Water Vapor

Atmospheric water vapor is measured with an aluminum oxide dew-frost point hygrometer (ref. 17). The sensing element consists of a small strip of aluminum which is anodized to provide a porous oxide layer. A very thin coating of gold is evaporated over this structure. The

aluminum base and the gold layer form the two electrodes of a capacitor whose impedance varies with the amount of water adsorbed on the porous surface.

This instrument provides dew-frost point temperatures (DFPT) from -110 degrees C to +40 degrees C for air sample temperatures from -65 degrees C to +40 degrees C. The air temperature is measured with a thermistor mounted on the sensor probe. The sensors are calibrated by the manufacturer, with a specified DFPT accuracy of  $\pm 2$  degrees C for  $-60 \text{ degrees C} < \text{DFPT} \leq +40 \text{ degrees C}$  and  $\pm 3$  degrees C for  $-110 \text{ degrees C} \leq \text{DFPT} \leq -60 \text{ degrees C}$ .

The sensors are re-calibrated in an environmental chamber at NASA-Lewis prior to installation on the aircraft. Calibration gas is provided by blending room air (DFPT = 10 degrees C), laboratory service air (DFPT = -40 degrees C), and liquid nitrogen boil-off (DFPT = -70 degrees C). The calibration is performed by comparing the aluminum oxide sensor output with the dew-frost point temperature measured by a cooled-mirror hygrometer. Because the sensor output varies with air-sample temperature, calibration is performed at room temperature, -20 degrees C and -40 degrees C. Upon removal from the aircraft, sensors are re-calibrated again at room temperature. Data are used only if the recalibrations are within the limits specified above.

The water vapor sensor is mounted in a de-iced airscoop of the type used on B-747 aircraft for measurement of outside air temperature. The water vapor sensor and the air temperature thermistor are mounted within the scoop as shown in figure 3. This mounting is similar to that of the "B-57 Air Sampler" described in reference 18. Because the scoop mount results in measurement at stagnation conditions, the water vapor-pressure calculated from the indicated DFPT is corrected by the ratio of static to total pressure, and then used to calculate the ambient water-vapor mixing ratio (in parts per million by weight, ppmw) and the ambient air dew-frost point.

Laboratory tests on the aluminum oxide hygrometer have shown several serious deficiencies which must be considered in evaluating the flight data. In these tests the response of the aluminum oxide hygrometer was compared to two cooled-mirror hygrometers; an aircraft-type undergoing response testing with the aluminum oxide hygrometer, and the laboratory standard cooled-mirror hygrometer mentioned previously. The DFPT readings of the two cooled-mirror hygrometers generally agreed to within 1 degree C. Their response was faster than the response of the aluminum oxide hygrometer by about a factor of 10, thus the cooled-mirror hygrometer data were used as actual dew-frost point temperature.

Response to step change in DFPT at constant sensor temperature. The time constant (to achieve 63 percent of a step change) of the aluminum oxide hygrometer was found to vary from 8 to 30 minutes depending on the gas (sensor) temperature and the magnitude and direction of the step change. In going from wet-to-dry conditions, the indicated DFPT was higher than the actual DFPT, and conversely, in going from dry-to-wet the indicated DFPT was lower than the actual DFPT.

Response to step change in sensor temperature at constant DFPT. As described in a previous paragraph, the indicated DFPT is dependent on the equilibrium sensor temperature. This effect is included in the data reduction through the use of temperature dependent calibration curves. In addition, however, the sensor has been found to have a transient response to changes in ambient temperature at constant DFPT. This response appears to be dependent on both the magnitude of the temperature change, and the rate of change. In response to a decrease in temperature of 20 degrees C at the rate of 2 degrees C/min, the indicated DFPT decreased during the temperature transient to less than the actual DFPT, and then slowly increased toward the true value with a time constant of approximately an hour. Thus a decreasing ambient temperature at constant dew-frost point will result in indicated DFPT values which are too low, and conversely increasing ambient temperature at constant dew-frost point will result in indicated DFPT values which are too high.

Sensor response during simulated climbout. The most severe gradients in ambient temperature and water vapor are encountered as the aircraft climbs to cruise altitude, with ambient temperature and DFPT both decreasing. The response characteristics described in the preceding paragraphs suggest that the aluminum oxide hygrometer would indicate too high a DFPT in response to the decreasing humidity, but would indicate too low a DFPT in response to the decreasing temperature. Thus the possibility exists for compensating effects. The simulated climbout data shown in figure 4 suggest this, although these data are from the only test of this type run to date, and the aluminum oxide hygrometer was reading too high at the beginning of the segment shown as a result of response to a previous temperature transient.

Response following saturation. The recovery of the sensor from saturated conditions, as would be encountered with the passage of the aircraft through clouds, was found to be very slow. The only available test data showed that, after having been subjected to saturated conditions for 40 minutes, the aluminum oxide hygrometer continued to indicate saturation for an additional 30 minutes after the air was no

longer saturated. The test was terminated at this time, and no data are available for the time required for the aluminum oxide hygrometer reading to return to the true DPPT. This slow response characteristic is apparent in the flight data also whenever prolonged saturation is indicated.

In spite of its stated limitations, it is felt that the water vapor measurements obtained with the aluminum oxide hygrometer may be of interest, and thus these data are reported, when available, as both dew-frost point temperature (DFPTA) and water vapor mixing ratio (WVMRA) in the DATA records (see table A-II). Whenever the indicated dew-frost point temperature is equal to the static air temperature, DPTAGA = "S", as a flag to the fact that saturated conditions have been encountered.

#### Cloud Detector

Flight test experience with the light-scattering particle counters included in the GASP systems has indicated that flight through clouds results in a significantly greater count of the largest size particles ( $D > 3$  micrometers) than is obtained in clear air. A simple cloud detector is thus available by observing the counting rate of the largest size particles. This signal is monitored for 256 seconds prior to each data recording. The time (in seconds) during which the cloud rate, CLDRT, is greater than a preset level, CLDHI, is interpreted as time in clouds (CLSEC; see table A-II). The CLDHI level was programmed on board the United airliner based on visual observation of a light haze, and corresponds to a local particle density (for  $D > 3$  micrometers) of 66,000 particles/cubic meter. If CLSEC > 0, CLTAG = "C". If cloud data are not available, CLTAG = "M".

The number of cloud encounters (CLAYR, see table A-II) is also available. Whenever clouds are detected (CLDRT > CLDHI), this is interpreted as a continuous encounter until cloud-free air is detected. This determination requires a second preset level, CLDLO. If  $n$  is the number of times that the cloud rate crosses CLDHI and CLDLO (or CLDLO and CLDHI) in succession, then CLAYR =  $(n+1)/2$ ; however, if  $n=0$  and CLSEC > 0, then CLAYR = 1. For the data on tape VL0004, CLDLO was set at CLDHI/8.

The cloud data are particularly useful as a supplement to the water vapor data. If there is a continuous or frequent indication of clouds, the dew-frost point temperature (DPPT) should remain at, or near, the static air temperature (SAT). However, if the DPPT remains equal to SAT in the absence of any cloud indication, the water vapor data should be considered suspect based on the slow response characteristics of the aluminum oxide hygrometer as

discussed previously.

### Flight Data

In addition to the air sample measurements, aircraft flight data are obtained with each data recording to precisely describe conditions when the data are acquired. Aircraft position, heading, and the computed wind speed and direction are obtained from the inertial navigation system. Altitude, air speed, and static air temperature are collected from the central air data computer in the aircraft. Vertical acceleration information (an indication of turbulence) is taken from the aircraft flight recording system. Date and time are provided by a separate GASP clock-calendar unit. The formats and units for these data are given in table A-II.

### Filter Samples

Atmospheric concentration data for sulfates, nitrates, and chlorides are provided by exposure and subsequent laboratory analysis of filter samples. Filter exposures are programmed to occur at altitudes greater than 9.6 kilometers on every third calendar day. Whether or not an exposure actually occurs depends on the availability of an unexposed filter. Filters are normally exposed for two hours; although shorter exposures may occur if the aircraft descends to an altitude less than 9.6 kilometers before two hours have elapsed. Filter data are included in the FLHT record (table A-I) for each flight. If an exposure occurs, FILEX = "T", and date, time, altitude and position for the beginning and end of the exposure are reported. If data from the laboratory analysis are available, FDATA = "T", and the type of filter as well as the constituent data are reported. The data from the laboratory analysis (in micrograms/filter) are divided by the integrated filter flow rate (in ambient cubic meters), and data are reported as micrograms/cubic meter.

Single filter apparatus. The air inlet probe and the filter sampling system are described in reference 4. Briefly, the filter sampling apparatus contains a single filter holder which is inserted into a 7.62 cm diameter duct for sampling, then retracted and stored; all on command from the GASP system control unit. The filter mechanism is stainless steel and is pressure tight. The filter holder can accommodate different types of filter material as appropriate to the atmospheric constituents of interest.

Filter preparation. All filter exposures for which data are reported on tape VL0004 were made using IPC-1478 filter

paper. This is a low resistance, cellulose type material made from second cut cotton linters with cotton scrim backing for added strength. This paper was specially designed for high altitude air sampling and thus features low pressure drop, high flow rate, and good retention for small airborne particles. This paper is impregnated with dibutoxyethylphthalate during manufacture to improve collection efficiency.

Prior to use, this paper must be washed to remove residual amounts of water soluble contaminants (ref. 19). Using a coarse fritted disc funnel (to support the filter paper), a 0.1 M HCl solution saturated with dibutoxyethylphthalate is vacuum-drawn through the filter for at least two minutes and until air permeates the filter. In a similar manner, each filter is then rinsed with six separate 30-35 ml portions of deionized water also saturated with dibutoxyethylphthalate. After overnight vacuum drying, samples from each wash group are analyzed for background levels of contamination to verify the washing procedure.

Upon acceptance, the group of filters is transferred to a clean room for filter holder assembly and sealing. The filters for which data are reported on tape VL0004 were sealed in clean nylon bags to prevent contamination during shipping and handling. After filter exposure and removal from the aircraft, the assembly was re-bagged and carefully re-packaged for return shipment and analysis.

Filter analysis. Prior to analysis, each filter was cut into four equal quarter segments to permit constituent analysis by separate techniques. Nitrate and chloride ion concentrations were determined by an electrochemical method; the specific ion electrode. This procedure consists of wetting a filter segment with 10 ml of 0.05 M sulfuric acid for 3-5 minutes. Then, with special electrodes immersed in the extracting solution, the specific ion potential produces a meter reading from which the ion concentration is determined by comparison with a calibration curve. The sensitivity of this method for nitrate and chloride ion determination is approximately  $\pm$  1 microgram per filter.

Sulfate ion was determined indirectly by treating the filter paper with a known amount of barium ion ( $Ba^{++}$ ) and measuring the amount that remained after reaction with the sulfate ion ( $SO_4=$ ). The decrease in the amount of barium ion in solution is directly related to the sulfate content of the sample; however, the apparent sulfate content of the samples was found to increase as the filter was aged. This unexplained interference was eliminated by pre-exposure of the filter segments to bromine fumes for up to one hour before the analysis was performed.

Barium ion is readily measured using flame emission spectroscopy; however, the solubility of BaSO<sub>4</sub> must be controlled by reducing its acidity to a pH of 4-5, and calcium interference must be avoided. Thus, an acetate buffer solution is added to control acidity, and ammonium oxalate is added to precipitate calcium without precipitating barium. The sensitivity of this method for sulfate ion determination is approximately  $\pm 1$  microgram per filter.

The net amount of any constituent on a filter was deduced by subtracting the background levels from two reference filter blanks which were removed from unexposed filter holder assemblies. The background levels for both references were very low and nearly identical. No adjustment for any contamination due to handling and shipping was made.

#### Bottle Samples

Atmospheric concentration data for trichlorofluoromethane (P-11) were obtained by exposure and subsequent laboratory analysis of whole air "grab" samples. Bottle exposures are programmed to occur at altitudes greater than 9.3 kilometers on every third calendar day, provided that an unexposed bottle is available. Bottle data are included in the FLHT record (table A-J) for each flight. If an exposure occurs, SBUEX = "T", and date, time, altitude, and position for the beginning and end of the exposure are reported. If data from the laboratory analysis are available, SDATA = "T" and constituent data are reported in units of parts per trillion by volume (pptv). During a bottle exposure, the GASP system is in a continuous record mode (MODE = 10, see table A-I) to provide a record of the atmospheric conditions which the aircraft encountered during the exposure period.

Sampling system. The sample is taken from a 1.90 cm stainless steel line, which is connected to the inlet probe through an expanded duct section. The sample line is continuously purged, with the aid of a bypass line installed just upstream of the sample bottle unit, to clear the duct wall surfaces of possible contamination by adsorbed chlorofluoromethanes.

Each sample bottle unit consists of four one-liter stainless-steel cylindrical sample bottles which have been electropolished, cleaned, and specially prepared for sampling. Hand operated bellows valves are attached at each end of the bottle to form an integral sub-assembly and to facilitate handling and processing procedures. Each sample bottle sub-assembly is connected in series to individual inlet and exit solenoid valves which operate on remote

command from the GASP system control unit.

Bottle exposures are normally five minutes in duration. During this time, both the inlet and exit solenoid valves are open. The sampling time was selected to provide at least ten total volume changes to purge the bottle and sample lines prior to entrapment of the sample. The sample flowrate through the bottle is limited to eight actual liters/minute by an orifice installed in the line downstream of the exit valve.

Sample bottle preparation. The bottle sub-assemblies are baked at approximately 300 degrees C for 40 hours or more, during which they are continuously purged with pure helium at a flow rate of 100 standard cc/minute. The final fill pressure is about 172 kPa. At least one bottle from each batch group is pumped down to sub-atmospheric pressure and stored for about a day to allow for wall desorption, and then analyzed for halocarbons. Upon zero level verification, the bottle sub-assemblies are installed in sample bottle units. Each unit is then leak checked with the inlet and exit sample lines evacuated using a helium mass spectrometer leak detector.

Trichlorofluoromethane (F-11) analysis. Bottle samples from which data are included on tape VL0004 were analyzed at Lewis utilizing a gas chromatograph with an electron capture detector. For determining F-11 concentrations, the chromatograph was equipped with a Porasil C column (100-150 mesh, 3.2 mm dia. x 4.0 m long) maintained at a temperature of 60 degrees C. A sample loop volume of 20 cc at nominally 13 kPa was flushed into the chromatographic column by helium carrier gas flow at about 38 cc/min. The chromatographic retention time was nominally nine minutes. The electron capture detector element was a tritium impregnated scandium foil type maintained at a temperature of 240 degrees C. Instrument sensitivity was determined to be less than 10 pptv.

Calibration was obtained by inter-laboratory comparisons of standards supplied by NOAA Environmental Research Laboratories (Boulder, Colorado) and Washington State University. These standards were derived from the "Halocarbon Analysis and Measurement Techniques Workshop" held at Boulder on March 25-26, 1976. A peak height comparison with these known calibration gases was used to obtain the data included on tape VL0004. Duplicate determinations were made for each sample and the results were averaged. Measurement precision was estimated to be about  $\pm$  5 percent.

Sample pressure considerations. Each whole air sample from which data are reported here was obtained at a pressure

slightly above the ambient pressure at the exposure altitude. Concern about adsorption-desorption of halocarbon from the walls of the sample containers at low sample pressures has been expressed by participants at the Boulder Workshop, and effects have been observed in recent work at the NOAA Environmental Research Laboratories (ref. 20). Tests at Lewis have shown that when unstable wall conditions exist, they are revealed by the initial zero halocarbon check after storage at low pressure (see Sample bottle preparation). Our tentative conclusion is that the effects are minimal for the sample data reported.

#### Tropopause Pressure Data

The National Meteorological Center (NMC) is presently maintaining a library of gridded meteorological data fields accessible on various disk and magnetic tape systems (ref. 21). Briefly, the data are interpolated to points on the NMC 65 X 65 grid, a square matrix map transformed from a polar stereographic map of the Northern Hemisphere. Among these gridded data are tropopause pressures, available on a twice daily basis (0000 and 1200 GMT).

The NMC tropopause pressure data arrays are included, when available, for the dates of the GASP flights to provide independent data for analysis of the constituent behavior. The NMC reporting periods for which these data appear on tape VL0004 are given in table II. The tropopause pressure arrays form a separate file (see appendix A) following the GASP data. Each array (4225 points) is written as seven TRPR records (table A-III). Coordinates for these data are the NMC 65 X 65 matrix. The relations for obtaining latitude and longitude from the NMC coordinates are given in appendix B. The aircraft location for each GASP DATA record is given both in NMC coordinates and latitude and longitude (see table A-II).

The tropopause pressure corresponding to each GASP data location is obtained by time and space interpolation from the NMC arrays. These pressures and the corresponding geopotential heights for the standard atmosphere are included in the GASP DATA records (TRPRMB and TRPRHM in table A-II). For normal interpolations (within a 12 hour interval) TPTAG = " ". If however, NMC data are missing for one reporting period such that the interpolation must be performed within a 24 hour interval, TPTAG is set = "L". If NMC data are missing for two or more consecutive reporting periods the time interpolation is not performed. In this case if the time of the GASP data point is within six hours of an NMC reporting period for which data are available, the space interpolated values at that reporting period are returned and TPTAG is set = "E", but if the time of the GASP

data point is not within 6 hours of an NMC reporting period for which data are available, TRPRMB and TRPRHM are set = 0, and TPTAG is set = "M". Whenever tropopause pressure values are available, DELP = TRPRMB - PAMB, and DELHGT = ALTMAV - TRPRHM are also reported.

From September 1974, through mid-December 1975, the location of the tropopause surface archived by NMC was determined by means of the Flattery global analysis method (ref. 22). This procedure made use of the vertical temperature profiles calculated for each NMC grid point, and tested the slope of the profile curve upwards from the first mandatory pressure level. However, as of December 17, 1975, (1200 GMT), the determination of the tropopause pressure surface has been formulated using a different analysis scheme. This change adopts a procedure conceived by Gustafson (ref. 23) which attempts to model the tropopause in terms of the potential temperature, which is a meteorologically significant height indicator. The method is based on climatological observations that the tropopause surface is generally in phase with pressure variations along potential temperature surfaces in the lower stratosphere. The modeled tropopause is constrained to lie near various, pre-selected, potential temperature surfaces, depending on month and geographical location.

The Gustafson method first calculates a potential temperature, THETA, profile above each of the 4225 NMC grid points from the ambient temperature, T, at each of the reported pressure levels, p, from the following definition of the potential temperature:

$$\text{THETA} = (T) (100/p)^{.2857} \quad (2)$$

This profile is then scanned downward, and delta THETA/delta p is evaluated for each layer, until a distinct stability transition occurs near the expected THETA location of the mean tropopause. The temperature at the top of this layer is defined as the tropopause temperature. Next, temperatures are calculated upwards from the bottom of the layer assuming pre-selected tropospheric lapse rates (depending on temperature range). The pressure at which this profile attains a temperature equal to the previously determined tropopause temperature is defined as the tropopause pressure. Many details have been omitted from this brief description, and the reader would be best advised to refer to reference 23.

The differences between the tropopause pressures identified by the Gustafson and Flattery methods are significant. These differences are apparent in the monthly zonal averages at 5 degree latitude intervals shown in table

III. Here, the values for January through November 1975 were obtained with the Flattery analysis, and values for January through August 1976 were obtained with the Gustafson method. Since the NMC changeover occurred in mid-December 1975, values for that month are a composite. From the table, it is apparent that not only does the current (Gustafson) analysis render tropopause pressures greater than those derived from the previous (Flattery) method, but that the differences increase toward the equator. We believe that the tropopause locations south of 30 degrees N, as reported after December 17, 1975, are suspect, and should be used with caution in analyzing GASP data. North of 30 degrees, the new tropopause pressures seem to fall within the statistical range of observed, mean pressures reported by Reiter (ref. 24) for the North American continent.

#### SELECTED ANALYSES

On two occasions during February 1976, United N4711U and Pan Am N655PA were on the same flight route within 24 hours of each other. Data from these flights are presented here as they provide a comparison of the measurements made by the two systems.

The route from San Francisco to Honolulu was flown by both aircraft, at 10.7 km, about 10 hours apart on February 2nd and 3rd. Data from these flights are shown on figure 5. The ozone mixing ratio and static air temperature records for both flights suggest minor penetrations into the stratosphere near 127 deg W and 147 deg W. In between these longitudes, the flights are clearly in the troposphere.

The NMC archived tropopause pressures along the flight route are also shown on each figure. When compared with the flight altitude, these tropopause pressures indicate stratospheric flight from 125 deg W to 150 deg W. This is not substantiated by the GASP ozone and temperature records. Although the variations in the tropopause pressures along the flight route are generally inversely related to the variations in ozone, it appears that the NMC analysis has underestimated the height of the tropopause.

Again on February 5th and 6th, both N4711U and N655PA were flying the same route, this time from Los Angeles to Honolulu. Data from these flights are shown in figure 6, where fig. 6a) is N4711U eastbound, fig. 6b) is N655PA westbound, and fig. 6c) is N4711U westbound. Note that the altitude of the eastbound flight was 0.6 km higher than the altitude of the westbound flights, and that the total time interval spanned by these flights was approximately 24 hours. In all cases, the ozone and temperature data show that the eastern third of each flight was in the

stratosphere. This is substantiated by the NMC tropopause height data, although the indicated mid-flight tropopause penetrations are from 2 to 5 degrees farther west than would be estimated from the ozone and temperature data.

In figures 6a) and 6c) dew-frost point temperatures (DFPT) as measured by the aluminum oxide hygrometer on N4711U are shown. These data provide some insight into the response characteristics of this sensor.

During the western half of the flight shown in fig. 6a), the aircraft was in the troposphere, the particle counter was registering continuous cloudiness, and the water vapor sensor was saturated. About 15 minutes after the aircraft entered the stratosphere, the sensor began returning unsaturated dew-frost point temperatures. The increase in indicated DFPT between 130 deg W and 125 deg W occurred even though the aircraft was penetrating farther into the stratosphere. This trend in DFPT may be a sensor response to the increasing static air temperature (see Water vapor - Response to step change in sensor temperature at constant DFPT ).

On the westbound flight shown in figure 6c), the aircraft entered the stratosphere during climbout from Los Angeles. From 122 deg W to 128 deg W the static air temperature was constant, and the indicated dew-frost point temperature continued to decrease. The rapid drop in indicated DFPT between 128 deg W and 132 deg W appears to have been caused by the decreasing temperature, since the ozone data suggest that the aircraft was flying out of the stratosphere, and wetter, not drier, conditions would be expected. Westward from 132 deg W, the static air temperature remained nearly constant, and the dew-frost point temperature increased as the flight entered the troposphere. The water vapor sensor indicated saturated conditions, and the particle counter showed continuous cloudiness from 147 deg W throughout the remainder of the flight.

Since only a few filter and bottle exposures occurred during the flights on tape VL0004, the concentration data and related exposure information are presented in tables IV and V in addition to their inclusion on the tape. Whenever it was clear from the GASP ozone and temperature data and/or the NMC tropopause pressure data that the exposure was tropospheric or stratospheric, this is indicated in the tables.

The results of the filter analyses (table IV) showed a wide variability in sulfate ( $\text{SO}_4^{2-}$ ) concentrations from 0.012 to 0.185 micrograms/cubic meter. Nitrate ( $\text{NO}_3^-$ ) concentrations were all less than .1 micrograms/cubic meter and appeared to increase or decrease in phase with the

sulfate levels. Chloride (Cl-) concentrations were all below 0.01 micrograms/cubic meter indicating no significant collection. Because the background concentration levels of the reference filters were very low for all species, the uncertainty for the reported concentration data is presumed to be no greater than the lowest level reported for each constituent.

The trichlorofluoromethane mixing ratio data from the three bottle exposures (table V) were nominally equal (102-106 pptv). All exposures were in the troposphere as verified by the ozone and tropopause pressure data. The sample pressures shown in table V were between static (ambient) and total pressure for each exposure. Although the GASP F-11 data are too limited to support any conclusions about variability of this species, it can be observed that these data are within the range of measurements obtained across the Alaskan troposphere in May 1975 by Robinson et. al. (ref. 25).

#### CONCLUDING REMARKS

Atmospheric constituent data and related flight and meteorological data obtained during several flights of GASP-equipped United Airlines and Pan American World Airways B-747's from December 26, 1975 - March 25, 1976 are now available. Tropopause pressure fields obtained from NMC data archives for the dates of the GASP flights are included as a supplement to the GASP data. These data may be obtained as GASP tape VL0004 from the National Climatic Center, Federal Building, Asheville, NC, 28801. Flight routes and dates, instrumentation, data processing procedures, tape specifications and formats, and selected analyses are discussed in this report.

#### ACKNOWLEDGEMENTS

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Ozone measurement	- M. W. Tiefermann
Water Vapor measurement	- T. J. Dudzinski
Cloud detector and particle measurement	- T. W. Nyland
Filter preparation and analysis	- D. A. Otterson
Sample bottle preparation and analysis	- G. M. Boyd

Specific questions may be addressed to the authors, or to any of the above individuals.

## REFERENCES

1. Grobecker, A. J.; Coroniti, S. C.; and Cannon, R. H., Jr.: Report of Findings: The Effects of Stratospheric Pollution by Aircraft. DOT-TST-75-50, Dept. of Transportation, 1974.
2. Environmental Impact of Stratospheric Flight: Biological and Climatic Effects of Aircraft Emissions in the Stratosphere. Nat. Acad. Sci., 1975.
3. Perkins, Porter J.; and Reck, Gregory M.: Atmospheric Constituent Measurements Using Commercial 747 Airliners. NASA TM X-71469, 1973.
4. Perkins, Porter J.; and Gustafsson, Ulf R. C.: An Automated Atmospheric Sampling System Operating on 747 Airliners. NASA TM X-71790, 1975.
5. Holdeman, J. D.; and Lezberg, E. A.: NASA Global Atmospheric Sampling Program (GASP): Data Report for Tape VL0001. NASA TM X-71905, 1976.
6. Falconer, Phillip D.; and Holdeman, James D.: Measurements of Atmospheric Ozone Made From a GASP-Equipped 747 Airliner: Mid-March, 1975. Geophys. Res. Lett., vol. 3, no. 2, Feb., 1976, pp. 101-104.
7. Holdeman, James D.; and Falconer, Phillip D.: Analysis of Atmospheric Ozone Measurements Made From a B-747 Airliner During March 1975. NASA TN D-8311, 1976.
8. Holdeman, James D.; and Lezberg, Erwin A.: NASA Global Atmospheric Sampling Program (GASP): Data Report for Tape VL0002. NASA TM X-73484, 1976.
9. Holdeman, James D.: NASA Global Atmospheric Sampling Program (GASP): Data Report for Tape VL0003. NASA TM X-73506, 1976.
10. Official Airline Guide. Int. Ed., published monthly, Rueben H. Donnelley Corp.
11. Bowman, Lloyd D.; and Horak, Richard F.: Continuous Ultra-violet Absorption Ozone Photometer. Anal. Instrum., vol. 10, 1972, pp. 103-108.

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12. Reck, Gregory M.; Briehl, Daniel; and Perkins, Porter J.: Flight Test of a Pressurization System Used to Measure Minor Atmospheric Constituents from an Aircraft. NASA TN D-7576, 1974.
13. Saltzman, Bernard E.; and Gilbert, Nathan: Iodometric Micro-determination of Organic Oxidants and Ozone. Anal. Chem., vol. 31, no. 11, Nov. 1959, pp. 1914-1920.
14. McMillan, R. D., Jr.: Application of a Precision Ozone Generator in Calibration of Ozone/Oxidant Analyzers and Inlet Sample Air Systems. AID 72415(61-66), Instru. Soc. Am. 1972.
15. Boberg, John E.; and Levine, Myron: Catalytic Filtration of Ozone in Airborne Application. J. Eng. Ind., vol. 84, no. 1, Feb. 1962, pp. 42-48.
16. Ozone Problems in High Altitude Aircraft. Aerospace Information Report 910, SAE, Nov. 1965.
17. Goodman, P.; and Chleck, D.: Calibration of the Panametric Aluminum Oxide Hygrometer. Anal. Instrum., vol. 7, 1969, pp. 233-235.
18. Hilsenrath, Ernest: Aircraft Water Vapor Measurements Utilizing an Aluminum Oxide Hygrometer. J. Appl. Meteorol., vol. 13, no. 7, 1974, pp. 812-819.
19. Gandrud, Bruce W.; and Lazarus, Allan L.: Design of System for Removing Water-Soluble Materials from IPC-1478 Filter Paper. Environmental Science and Technlology, vol. 6, no. 5, May 1972, pp. 455-457.
20. Schmeltakopf, A. L.; Goldan, P. D.; Harrop, W. J.; Thompson, T. L.; Albritton, D. J.; McFarland, M.; Sapp, A. E.; and Henderson, W. R.: Balloon-Borne Stratospheric Grab-Sampling System. Rev. Sci. Instr., Dec. 1976.
21. Gelhard, Robert: NMC Archives. Office Note 108, U.S. Dept. Commerce, 1975.
22. Flattery, Thomas W.: Spectral Models for Global Analysis and Forcasting. Proceedings of the Sixth AWS Technical Exchange Conference. AWS-TR-242, Air Weather Service, 1971, pp. 42-54.

23. Gustafson, A. W.: Objective Analysis of the Tropopause.  
NMC-TM-65-33, U.S. Dept. Commerce, 1965 (available from  
National Weather Service, Silver Springs, Md.).
24. Reiter, E. R.: Stratospheric-Tropospheric Exchange Processes.  
Rev. Geophys. Space Sci., vol. 13, no. 4, Aug. 1975, pp. 459-474.
25. Robinson, E.; et al.: Detailed Halocarbon Measurements Across  
the Alaskan Troposphere. Geophys. Res. Lett., vol. 3, no. 6,  
June, 1976, pp. 323-326.

TABLE I - GASP FLIGHTS ON TAPE VL0004

## a) File 1 (N4711U)

	Flight Route	Departure Date	Data Time Interval (GMT)	Data
1	SPO-HNL	12/26/75	2227-0229	0
2	HNL-ORD	12/27/75	0432-1147	0
3	ORD-YYZ		1356-1426	0
4	YYZ-ORD		1651-1721	0
5	ORD-HNL		2013-0341	0
6	HNL-SFO	12/28/75	1956-2352	0
7	SFO-BOS	12/29/75	2038-0107	0
8	BOS-SPO	12/30/75	1508-2029	0
9	SFO-HNL		2255-0300	0
10	HNL-LAX	12/31/75	0458-0906	0
11	SPO-ORD	1/24/76	1849-2131	0 W
12	SFO-HNL	1/26/76	0412-0437	0 W
13	HNL-SFO		1020-1415	0 W
14	SPO-HNL		1749-2155	0 W
15	HNL-LAX	1/27/76	0017-0437	0 W
16	LAX-HNL		1807-2237	0 W
17	HNL-SFO	1/28/76	0104-0459	0 W
18	SFO-ORD		1840-2135	0 W
19	ORD-LAS	1/29/76	1702-1945	0 W
20	LAS-ORD		2204-0024	0 W
21	ORD-LAX	1/30/76	2228-0138	0 W
22	LAX-JPK	1/31/76	2041-0051	0 W
23	LAX-HNL	2/02/76	0028-0485	0 W
24	HNL-SFO		1020-1420	0 W
25	SPO-HNL		1736-2148	0 W
26	HNL-LAX	2/03/76	0008-0421	0 W
27	LAX-JFK		2034-0017	0 W
28	JFK-LAX	2/04/76	1734-2224	0 W
29	LAX-HNL	2/25/76	0048-0528	0 W
30	HNL-LAX		1931-2346	0 W
31	LAX-DEN	2/06/76	0141-0251	0 W
32	LAX-HNL		2146-0206	0 W
33	ITO-ORD	2/07/76	0654-1349	0
34	SFO-HNL	2/10/76	2223-0233	0
35	HNL-LAX	2/11/76	0935-1349	0
36	LAX-ORD		1628-1854	0
37	ORD-LAX		2237-0152	0
38	LAX-ITO	2/12/76	2020-0043	0
39	ITO-LAX	2/13/75	0238-0632	0
40	LAX-ORD		0850-1126	0
41	ORD-PIT		1355-1420	0
42	PIT-ORD		1643-1718	0
43	ORD-LAX		1934-2248	0

Table I - a) Concluded

	Flight Route	Departure Date	Data Time Interval (GMT)	Data
44	LAX-SPO	2/14/76	0199-0141	0
45	SFO-LAX		0348-0408	0
46	LAX-ITO		2018-0025	0
47	ITO-LAX	2/15/76	0243-0658	0
48	LAX-JFK	2/24/76	2028-0018	0 W
49	JFK-LAX	2/25/76	1731-2211	0 W
50	LAX-HNL	2/26/76	0122-0612	0 W
51	HNL-SFO		1013-1355	0 W
52	SFO-HNL		1729-2212	0 W
53	HNL-LAX	2/27/76	0010-0406	0 W
54	LAX-ORD		2040-2325	0 W
55	ORD-JFK	2/28/76	0171-0217	0 W
56	JFK-LAX		1729-2221	0 W
57	LAX-HNL	2/29/76	0050-0545	0 W
58	HNL-SPO		2002-2344	0 W
59	SPO-HNL	3/01/76	2223-0252	0 W
60	HNL-ORD	3/02/76	0506-1130	0 W
61	ORD-LAS		1949-2249	0 W
62	LAS-ORD	3/03/76	2204-0013	0 W F
63	ORD-CLE	3/04/76	0235-0253	0 W
64	CLE-ORD		1421-1446	0 W
56	ORD-HNL		1735-0134	0 W
66	HNL-ORD	3/05/76	0433-1117	0 W
67	ORD-YYZ		1401-1546	0 W
68	YYZ-ORD		1834-1919	0 W
69	ORD-HNL		2202-0555	0 W
70	HNL-LAX	3/06/76	1048-1448	0 W
71	LAX-ORD		1638-1918	0 W
72	ORD-LAX		2231-0141	0 W
73	LAX-ITO	3/07/76	2003-0036	0 W

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- 1 O - Ozone  
 W - Water Vapor  
 F - Filter Exposure  
 B - Bottle Exposure

TABLE I - GASP FLIGHTS ON TAPE VL0004

## b) File 2 (N655PA)

	Flight Route	Departure Date	Data Time Interval (GMT)	Data
1	SPO-HND	1/22/76	2156-0743	0
2	HND-HKG	1/23/76	1039-1424	0
3	HKG-BKK		1555-1900	0
4	BKK-DEL		2057-0017	0
5	DEL-THR	1/24/76	0201-0521	0
6	THR-IST		0853-1111	0
7	IST-FRA		1300-1505	0
8	FRA-LHR		1652-1727	0
9	LHR-JFK		2046-0326	0
10	JFK-LHR	1/25/76	1540-2055	0
11	LHR-BRU		2258-2303	0
12	LHR-JFK	1/26/76	0909-1820	0
13	JFK-FCO	1/27/76	0248-0947	0
14	FCO-SNN		1219-1429	0
15	SNN-JPK		1619-2236	0
16	JPK-FCO	1/28/76	0226-0905	0
17	FCO-JFK		1213-2035	0
18	JFK-LHR	1/29/76	1547-2115	0
19	LHR-BRU		2251-2306	0
20	BRU-LHR	1/30/76	0912-0922	0
21	LHR-JPK		1215-1850	0
22	JPK-FRA		2344-0539	0
23	MUC-FRA	1/31/76	1202-1207	0
24	FRA-JPK		1521-2234	0
25	JPK-SPO	2/01/76	1429-1914	0
26	SPO-HNL	2/03/76	0316-0721	0
27	HNL-GUM		1027-1715	0
28	GUM-MNL		1920-2155	0
29	MNL-HKG		2335-0032	0
30	HKG-MNL	2/04/76	0510-0605	0
31	MNL-GUM		0381-1101	0
32	LAX-HNL	2/06/76	0346-0816	0
33	HNL-PPG		1038-1503	0
34	PPG-SYD		1719-2155	0
35	SYD-PPG	2/07/76	0708-1126	0
36	PPG-HNL		1534-1639	0
37	HNL-LAX		1941-0004	0
38	LAX-HNL	2/08/76	0502-0757	0
39	HNL-LAX	2/09/76	2234-0246	0
40	LAX-HNL	2/10/76	1733-2157	0
41	HNL-SPO	2/11/76	2251-0251	0
42	SPO-HND	2/27/76	2301-0855	P
43	DEL-THR	3/03/76	0244-0558	P
44	LHR-JPK	3/09/76	1132-1827	P

Table I - b) Concluded

	Flight Route	Departure Date	Data Time Interval (GMT)	Data
45	JPK-SPO	3/18/76	1521-2042	0 F B
46	SFO-HND		2254-0905	0
47	HND-HKG	3/19/76	1101-1441	0
48	HKG-BKK		1619-1914	0
49	BKK-DEL		2058-0000	0
50	DEL-THR	3/20/76	0140-1455	0
51	THR-IST		0857-1102	0
52	IST-FRA		1244-1446	0
53	FRA-LHR		1650-1725	0
54	LHR-JFK		1933-0206	0
55	JPK-LHR	3/21/76	1556-2102	0 B
56	LHR-BRJ		2226-2236	0
57	BRU-LHR	3/22/76	0805-0810	0
58	LHR-JFK		1026-1705	0
59	JFK-LHR	3/23/76	0101-0608	0
60	FRA-IST		1234-1419	0
61	IST-THR		1553-1758	0
62	THR-DEL		2150-0020	0
63	DEL-BKK	3/24/76	0201-0449	0 B
64	BKK-HKG		0701-0951	0
65	HKG-HND	3/25/76	0245-0535	0
66	HND-SPO		0753-1530	0

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1 O - Ozone  
 W - Water Vapor  
 F - Filter Exposure  
 B - Bottle Exposure

TABLE II - NMC TROPOAUSE PRESSURE DATA  
ON GASP TAPE VL0004

	From	Through
1	12/26/75, 1200 GMT	12/30/75, 1200 GMT
2	1/22/76, 1200 GMT	2/15/76, 1200 GMT
3	2/24/76, 1200 GMT	3/08/76, 1200 GMT
4	3/18/76, 1200 GMT	3/26/76, 0000 GMT

Table III - Zonal Averaged NMC Tropopause Pressure Data, January 1975 - August 1976

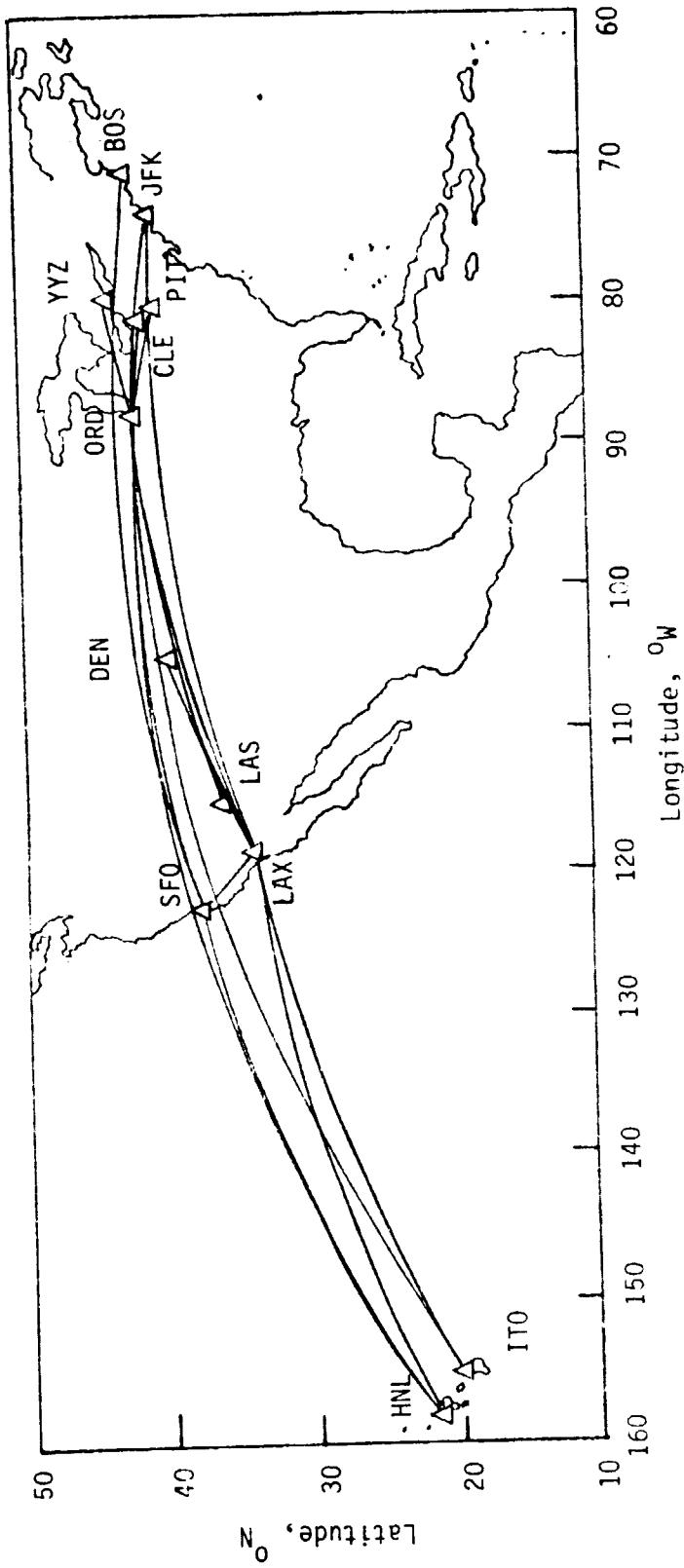
LATITUDE (Degrees North)														
	20	25	30	35	40	45	50	55	60	65	70	75	80	85
J	131.5	138.3	165.5	210.6	234.6	243.9	253.5	262.1	267.4	268.1	264.6	260.8	256.9	251.8
F	134.3	153.5	139.5	223.6	241.3	254.1	262.6	265.1	264.4	262.0	261.8	264.8	265.9	264.3
M	132.6	149.0	183.2	212.8	228.7	242.9	255.3	262.9	268.1	274.3	281.5	286.7	287.5	285.1
A	134.0	145.2	169.3	195.4	212.9	226.0	239.3	251.3	262.7	275.0	287.9	299.4	306.5	308.7
M	130.2	135.1	154.9	184.9	207.1	221.7	234.9	247.0	258.6	269.3	278.0	286.6	297.2	304.9
J	130.2	130.7	135.4	152.3	180.3	205.7	220.8	232.2	244.9	256.7	267.4	277.1	281.9	280.8
J	130.3	130.5	130.6	133.9	150.7	182.7	213.0	229.1	235.9	242.8	252.8	261.4	265.7	267.2
A	130.4	130.8	131.1	133.9	148.7	179.8	211.1	227.9	235.4	240.5	247.0	256.0	265.2	270.8
S	130.3	131.0	132.1	137.7	158.2	191.6	218.4	232.7	242.2	251.5	262.5	272.4	276.6	275.1
O	132.0	132.8	136.4	151.8	182.3	215.4	237.5	247.0	251.4	257.7	267.7	277.9	286.3	292.1
N	131.1	134.4	145.1	172.2	201.9	223.0	239.0	252.2	263.0	270.3	273.6	275.7	279.9	285.5
D	155.3	165.3	190.0	226.0	251.5	261.9	268.0	273.3	278.1	282.0	284.8	286.3	287.1	288.5
J	192.0	269.3	237.0	267.4	296.2	292.4	295.8	298.9	298.6	294.2	288.4	285.3	283.1	277.6
F	192.6	211.0	242.6	266.5	280.2	293.9	305.1	307.8	302.2	294.2	287.6	282.5	280.5	280.3
M	187.6	204.1	232.8	255.5	274.2	292.8	306.7	312.0	310.7	302.9	292.2	284.2	280.5	278.7
A	181.7	191.9	214.3	236.4	255.5	273.6	287.9	298.7	308.8	319.2	328.4	334.8	334.4	329.3
M	179.4	186.7	202.8	221.1	239.6	258.8	277.5	294.9	308.6	315.7	322.8	332.8	341.5	344.9
J	176.2	184.8	194.8	207.3	225.8	246.0	262.6	277.3	289.2	300.2	313.5	325.3	330.0	327.5
J	160.2	172.7	183.6	194.7	212.3	234.8	225.8	266.7	273.3	283.4	296.6	308.1	317.9	326.6
A	150.3	160.5	172.3	185.7	206.0	232.1	252.7	264.6	272.5	279.7	291.0	307.9	324.9	334.2

TABLE IV - FILTER DATA ON TAPE VL0004

GASP Identification							
Filter no.	411	Filter no.	401	Flight	503	Flight	508
File, flight	2,42		2,43		1,62		2,44
							2,45
Exposure Data							
Date	2/27/76	Date	3/03/76	Date	3/09/76	Date	3/18/76
Latitude, deg	40-35N	Latitude, deg	29-30N	Latitude, deg	38-42N	Latitude, deg	53-59N
Longitude, deg	152-141E	Longitude, deg	75-60E	Longitude, deg	112-91W	Longitude, deg	3-25W
Time, min	83	Time, min	120 (90, 30)	Time, min	109 (65, 44)	Time, min	120
Altitude, km	11.9	Altitude, km	10.7, 11.9	Altitude, km	11.3, 11.9	Altitude, km	10.7
Region	troposphere	Region	uncertain	Region	stratosphere	Region	uncertain troposphere
Constituent Data							
SO <sub>4</sub> =, $\mu\text{g}/\text{m}^3$	0.059	SO <sub>4</sub> =, $\mu\text{g}/\text{m}^3$	0.012	SO <sub>4</sub> =, $\mu\text{g}/\text{m}^3$	0.185	SO <sub>4</sub> =, $\mu\text{g}/\text{m}^3$	0.147
NO <sub>3</sub> =, "	0.070	NO <sub>3</sub> =, "	0.026	NO <sub>3</sub> =, "	0.098	NO <sub>3</sub> =, "	0.084
Cl-, "	0.007	Cl-, "	0.005	Cl-, "	0.008	Cl-, "	0.002
							0.005

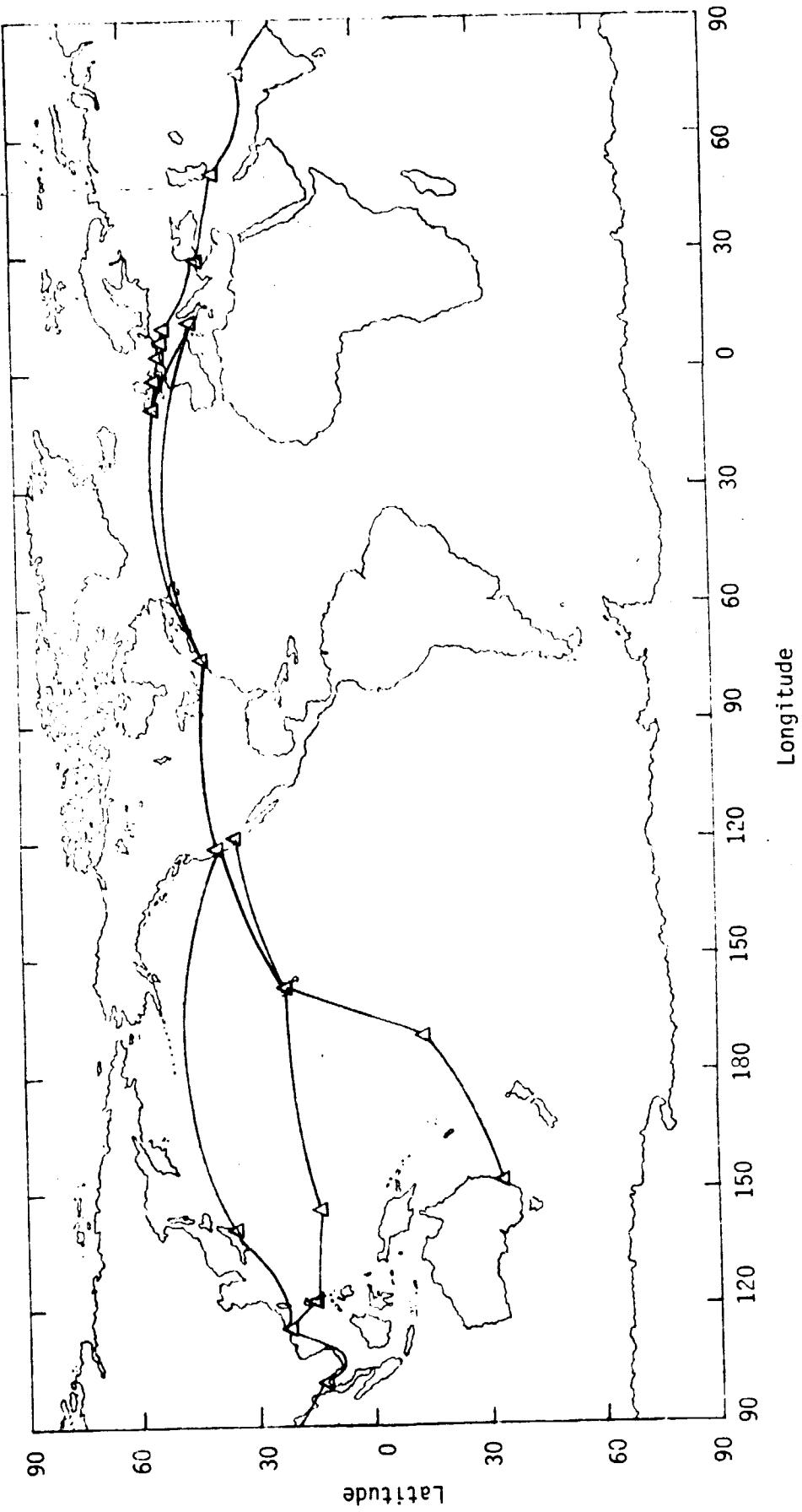
TABLE V - SAMPLE BOTTLE DATA ON TAPE VL0004

GAS IDENTIFICATION			
Bottle no.	10-1	10-2	10-3
Analysis no.	20	41	33
File, flight	2.45	2.55	2.63
SAMPLE DATA			
Date	3/18/76	3/21/76	3/24/76
Latitude, deg	41N	44N	26N
Longitude, deg	78W	65W	82E
Altitude, km	10.7	10.1	11.3
Region	troposphere	troposphere	troposphere
Pressure, kPa	32	36	29
CONSTITUENT DATA			
P-11, pptv	102	105	106

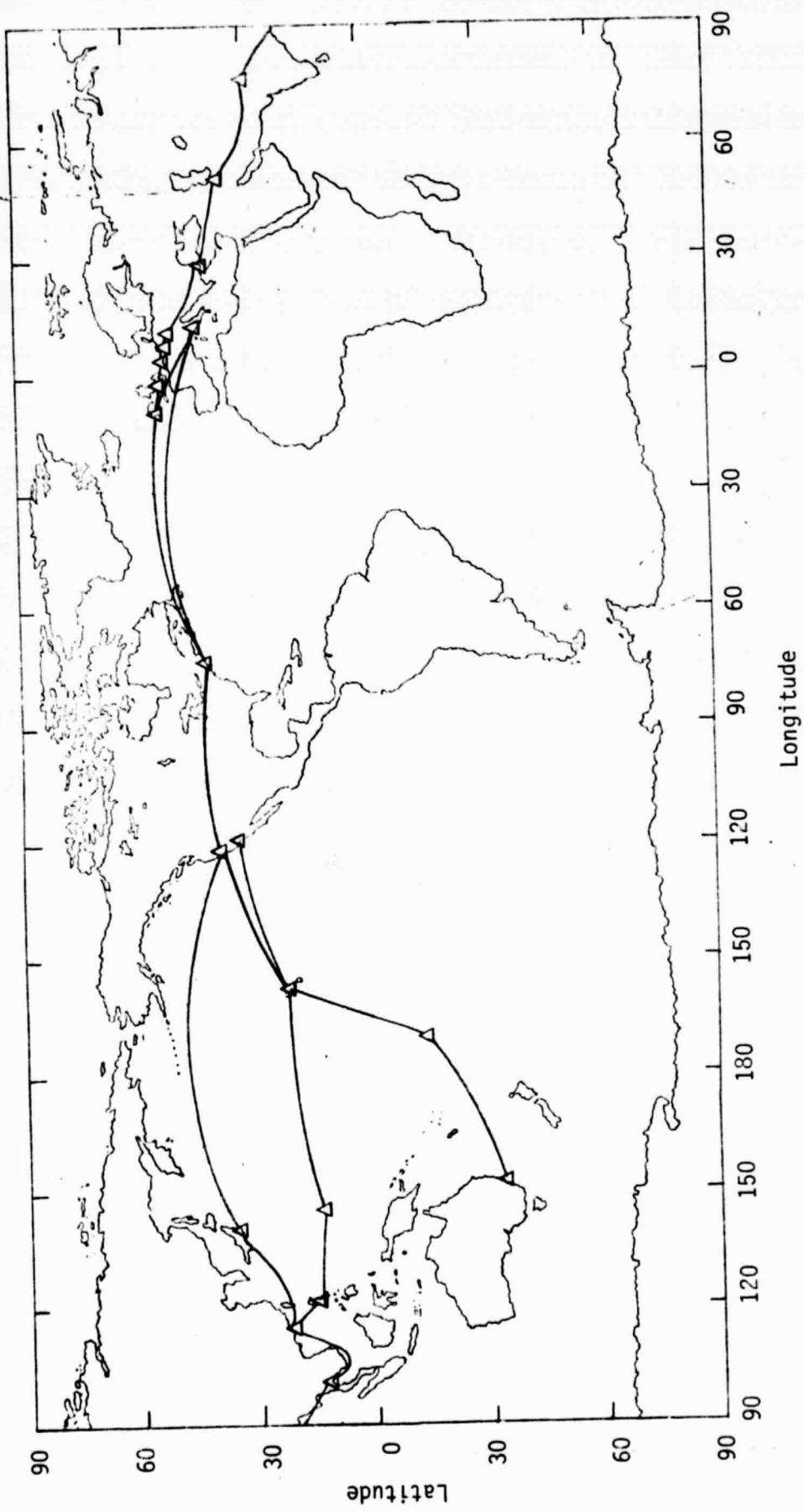


a) File 1 - United Airlines (N4711U)  
Figure 1. GASP Flight Routes for Tape VL0004

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b) File 2 - Pan American World Airways (N655PA)  
Figure 1. GASP Flight Routes for Tape VL0004



b) File 2 - Pan American World Airways (N655PA)  
Figure 1. GASP Flight Routes for Tape VL0004

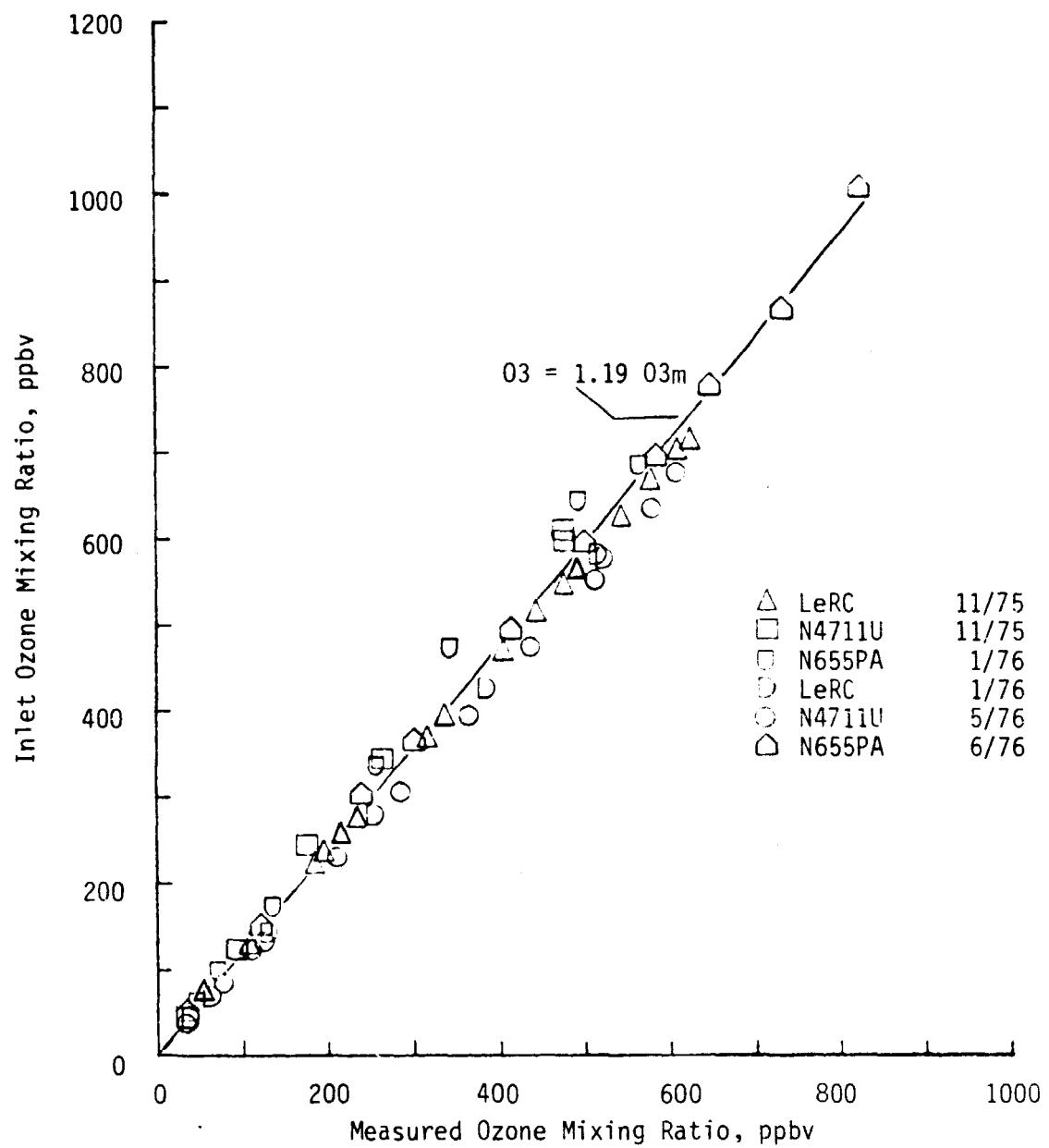


Figure 2. GASP System Ozone Destruction Test Results

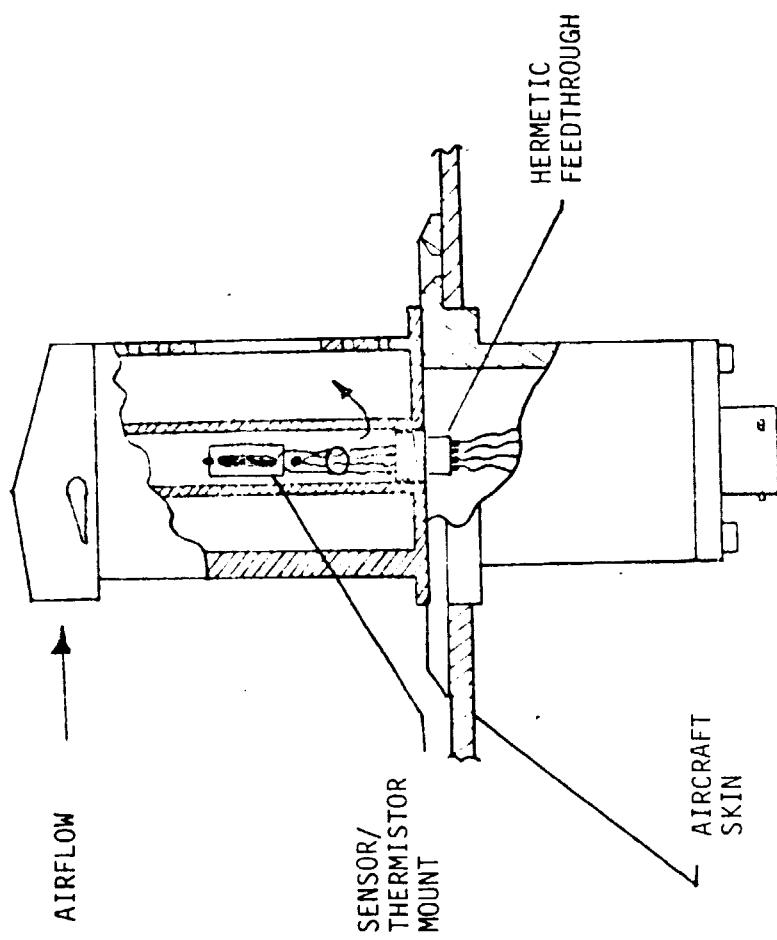


Figure 3 - GASP Water Vapor Sampling Probe/Sensor Configuration.  
Probe Model H102KD. Panometrics Sensor Model MIT-N  
Rosemount

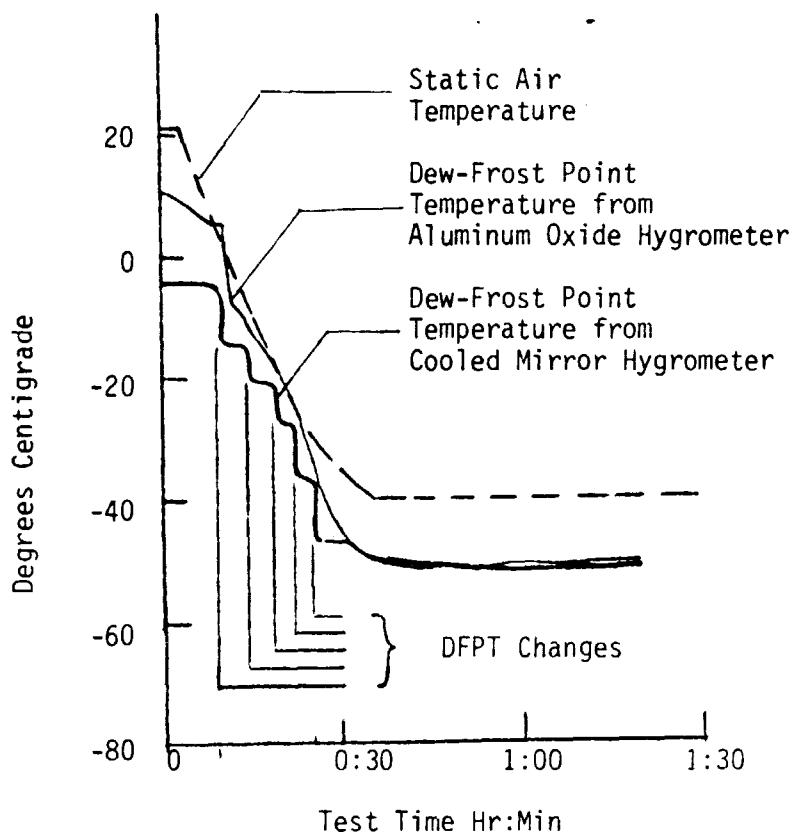


Figure 4 - Response of Water Vapor Sensor During Simulated Climbout (Decreasing Ambient Temperature and Dew-Frost Point).

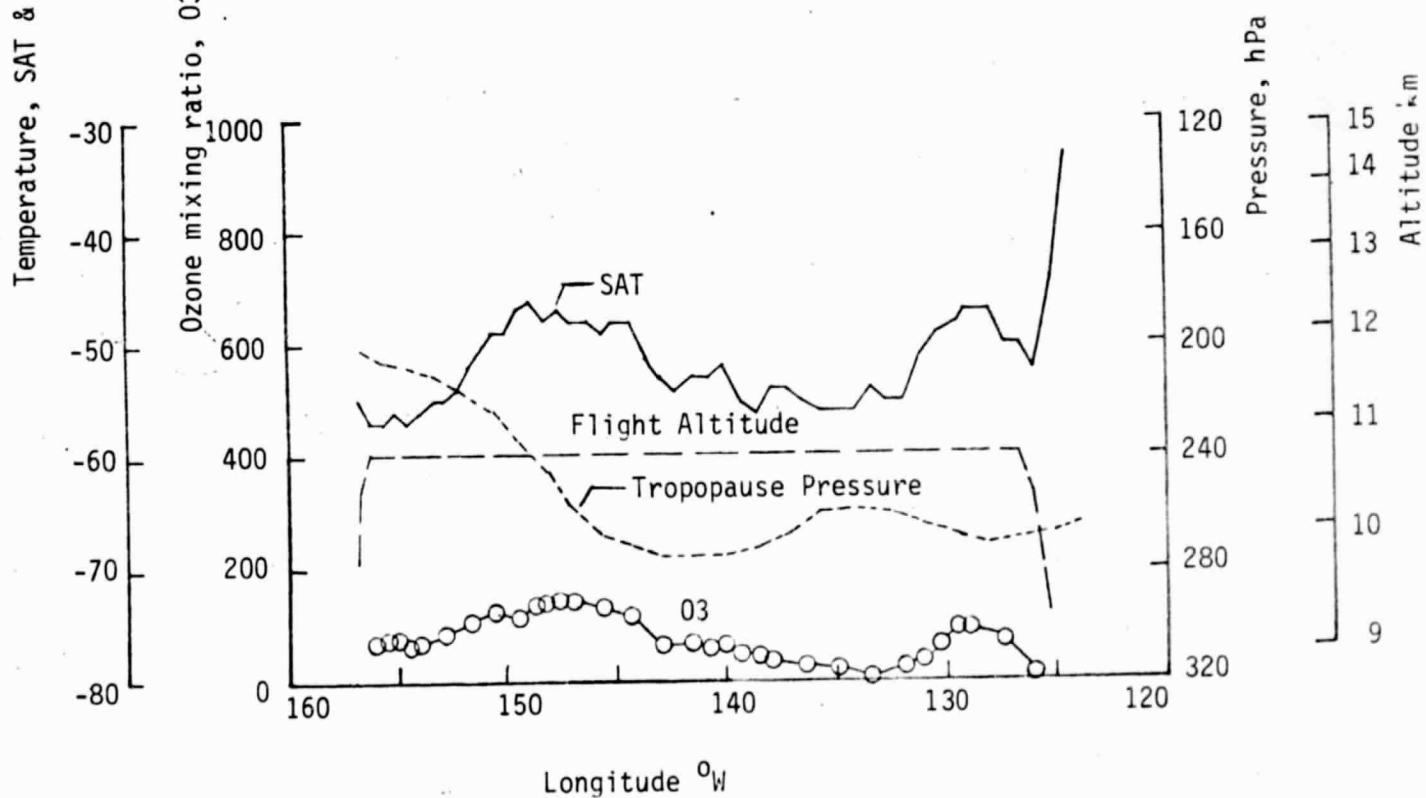
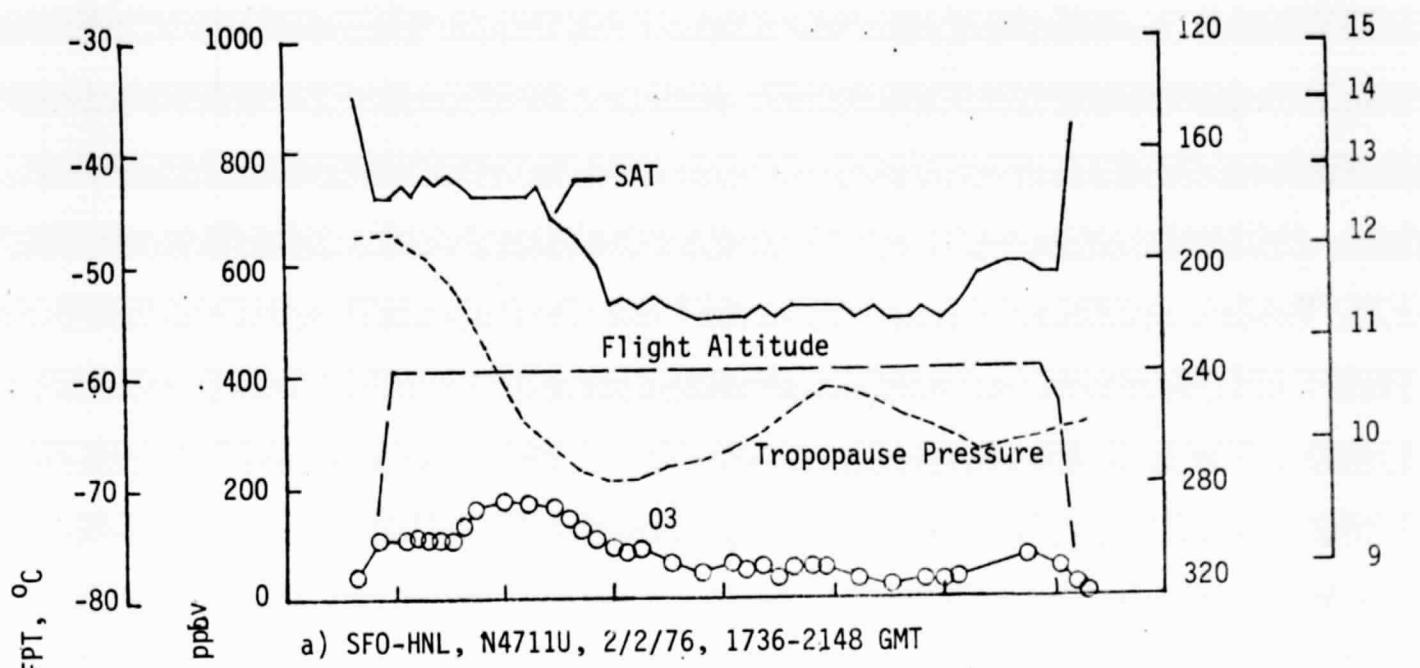


Figure 5 Flight records for 2/2-3/76. All data are from GASP and aircraft systems except for the tropopause pressures, which were time and space interpolated from NMC data archives

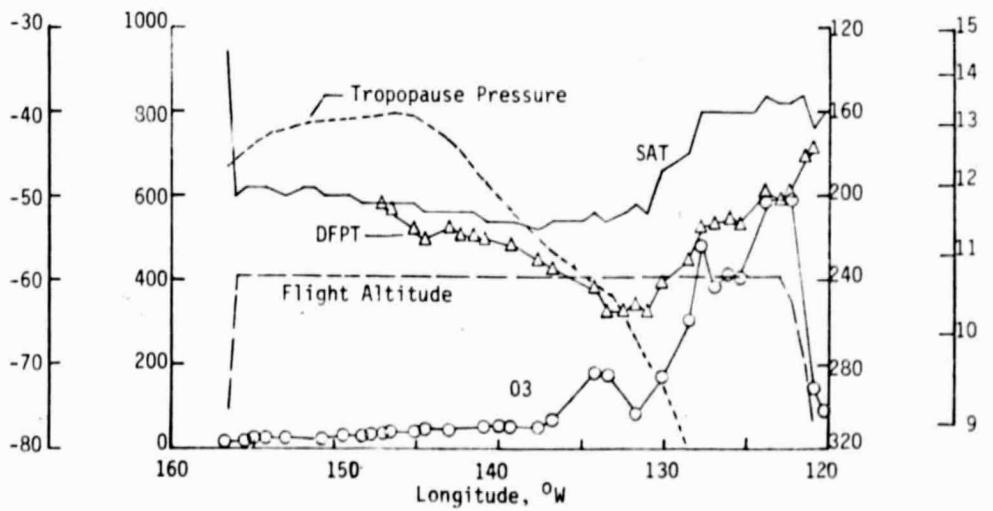
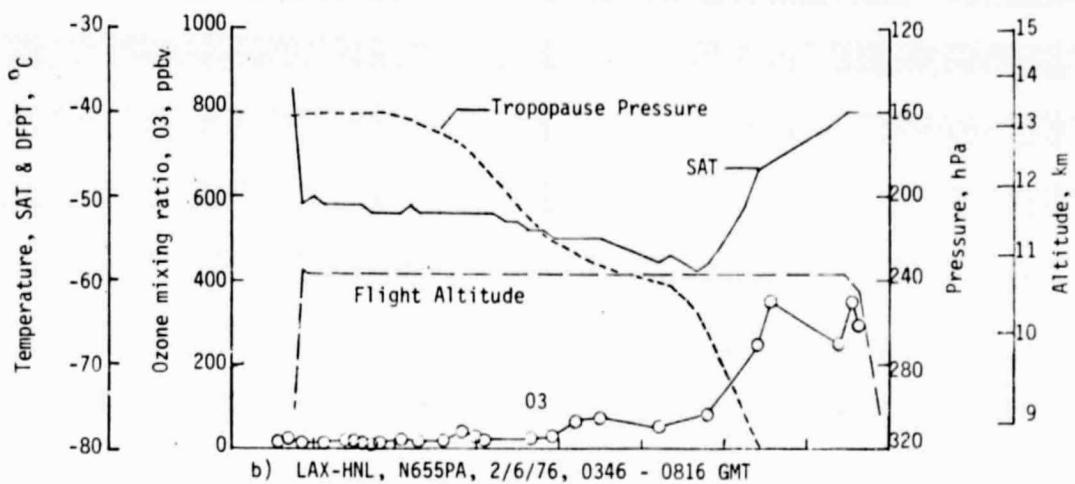
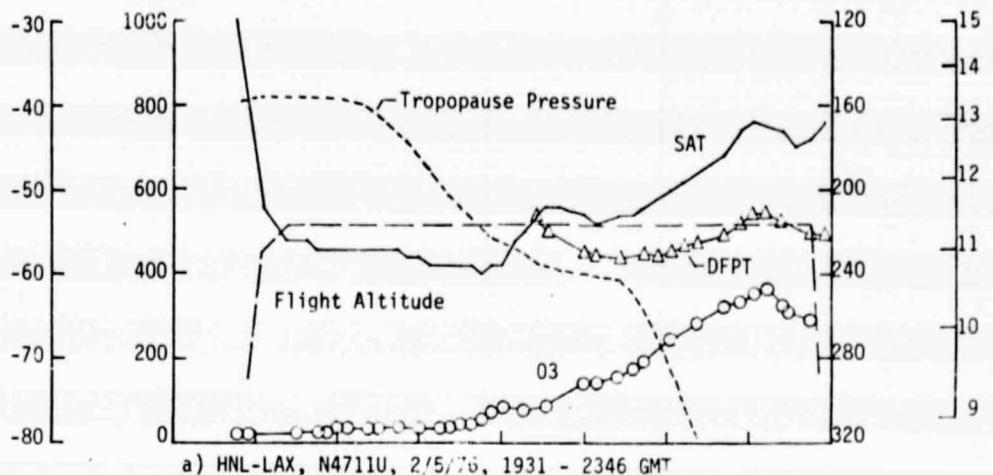


Figure 6 Flight records for 2/5-6/76. All data are from GASP and aircraft systems except for the tropopause pressures, which were time and space interpolated from NMC data archives

**APPENDIX A - Specifications for GASP Archive Tapes (VLXXXX)****GENERAL**

1. Tapes are written in EBCDIC format using nine track tapes.
2. Tape density is 800 BPI.
3. Physical records (blocks) are 4096 bytes.
4. The tapes are unlabeled, and contain one or more GASP data files followed by a tropopause pressure data file.

**GASP DATA FILE**

1. Each GASP data file contains data from a single GASP aircraft. Within each file, data are grouped and identified by flights (takeoff to landing) in chronological order.
2. The GASP data for each flight begins with a logical FLHT record (flight identification data), which is followed by logical DATA records (one for each data recording made during the flight). Both FLHT and DATA records contain 512 bytes, hence there are 8 logical records per physical record (block).
3. A FLHT record will always be the first logical record in a block. However, every block need not begin with a FLHT record (i.e., if there are more than seven DATA records in a flight). If the FLHT record plus the available DATA records for a flight do not fill an integer number of blocks, the unused logical records in the final block are padded with zeros creating PADD records. The diagram below shows how several short flights would be blocked.

Block	1	2	3
	F D D D D D P P	F D D D D D D D	D D P P P P P P
Logical Record	1 2 3 4 5 6 7 8	1 2 3 4 5 6 7 8	1 2 3 4 5 6 7 8

Block	4	5	6
	F D D D D D D D	D D D D D D D D	F D D D D D D D P
Logical Record	1 2 3 4 5 6 7 8	1 2 3 4 5 6 7 8	1 2 3 4 5 6 7 8

where F is a FLHT record  
 D is a DATA record  
 P is a PADD record

4. The first four bytes in each logical record identify the record type as FLHT, DATA, or PADD. Detailed specification of the parameters and formats for FLHT and DATA records are given in Table A-I and A-II respectively.

- a) In each FLHT record, the number of DATA records to follow is given by NDATA (Bytes 78-81), and the number of blocks in the flight is given by NBLOCK (Bytes 82-84).
- b) For the last DATA record of each flight, LBFLG (Byte 5) = "L"; for the last DATA record in each file, LBFLG = "G" if the following file is a GASP data file, and LBFLG = "T" if the following file is the tropopause pressure file; for all other DATA records, LBFLG = " ".

Note: DATA records with LBFLG ≠ " " will be followed by PADD records if the physical record (block) is not complete.

#### TROPOPAUSE PRESSURE DATA FILE

1. Following the GASP data, in a separate file, tropopause pressure data for the dates of the GASP flights are included. Data are currently available from the National Meteorological Center (NMC) twice daily for 4225 locations in the Northern Hemisphere. Coordinates for these data are the NMC 65X65 square matrix grid, transformed from a polar stereographic map of the Northern Hemisphere.
2. Each 65X65 tropopause pressure array is written as seven TRPR records. Each TRPR record is a physical record (block), and is the same length as the GASP physical records (4096 bytes). All TRPR records contain identification information. Specifications and formats for the TRPR records are given in Table A-III.

Table A-1 Format for PLHT Records

Bytes	Portran Name	Portran Format	Parameter Description, Units, and Comments
1-4	RECID	A4	RECID = "PLHT"
5-10	TAPID	A6	Original GASP tape number, GXXXX
11-25	ACID	A15	Aircraft ID: Airline and tail number
26-28	APTLV	A3	Airport of departure (3 letter code)
29-34	DATLV	I6	Date first DATA record this flight: Mo=29-30, Da=31-32, Yr=33-34
35-38	TIMLV	A4	Time (GMT) first DATA record this flight; Hr=35-36, Min=37-38
39-43	LATLV	F5.2	Latitude (deg) of APTLV
44	LALVT	A1	Hemisphere of LATLV: "N" or "S"
45-50	LONGV	F6.2	Longitude (deg) of APTLV
51	LOLVT	A1	Hemisphere of LONGV: "E" or "W"
52-54	APTAR	A3	Airport of arrival (3 letter code)
55-60	DATAR	I6	Date last DATA record this flight: Mo=55-56, Da=57-58, Yr=59-60
61-64	TIMAR	A4	Time (GMT) last DATA record this flight; Hr=61-62, Min=63-64
65-69	LATAR	F5.2	Latitude (deg) of APTAR
70	LAART	A1	Hemisphere of LATAR, "N" or "S"
71-76	LONAR	F6.2	Longitude (deg) of APTAR
77	LOART	A1	Hemisphere of LONAR, "E" or "W"
78-81	NDATA	I4	Number of DATA records for this flight
82-84	NBLOCK	I3	Total number of blocks for this flight
85-87	O3ID	A3	Ozone instrument ID number*
88-90	C0ID	A3	Carbon monoxide instrument ID number*
91-93	PCSID	A3	Particle counter sensor ID number*
94-96	PCEID	A3	Particle counter electronics ID number*
97-99	H2OID	A3	Water vapor sensor ID number*
100-102	HYGID	A3	Hygrometer ID number*
103-105		A3	Spare ID
106-108		A3	Spare ID
109-111		A3	Spare ID
112-114		A3	Spare ID

Table A-1 Continued

Bytes	Portran Name	Portran Format	Parameter Description, Units, and Comments
115-117		A3	Spare ID
118-122	D1	P5. 3	Smallest particle radius (micrometers) for PC range 1
123-127	D2	P5. 3	Smallest particle radius (micrometers) for PC range 2
128-132	D3	P5. 3	Smallest particle radius (micrometers) for PC range 3
133-137	D4	P5. 3	Smallest particle radius (micrometers) for PC range 4
138-142	D5	P5. 3	Smallest particle radius (micrometers) for PC range 5
143	LIMCHK	A1	LIMCHK="T" if ACC limit exceeded (NE . GT. 0) on any DATA record this flight; otherwise LIMCHK="F"
144	FILEX	A1	FILEX="T" if filter exposed this flight; otherwise FILEX="F"
145	PDATA	A1	PDATA="T" if filter data on tape; otherwise PDATA="F"
150-151	FILTN	I4	Filter pack number
152-161	PTYPE	I2	Filter type
162-167	FDATON	I6	Filter exposure start date: Mo=162-163, Da=164-165, Yr=166-167
168-171	PTIMON	A4	Filter exposure start time: (GMT): Hr=168-169, Min 170-171
172-176	PLATON	P5. 2	Filter exposure start latitude (deg)
177	PLAONT	A1	Filter exposure start latitude tag: "N" or "S"
178-183	PLONON	P6. 2	Filter exposure start longitude (deg)
184	PLOONT	A1	Filter exposure start longitude tag: "E" or "W"
185-190	PHTMON	P6. 0	Filter exposure start altitude (meters)
191-196	PDATOF	I6	Filter exposure stop date: Mo=191-192, Da=193-194, Yr=195-196
197-200	PTIMOF	A4	Filter exposure stop time (GMT): Hr=197-198, Min=199-200
201-205	PLATOF	P5. 2	Filter exposure stop latitude (deg)
206	PLAOF	A1	Filter exposure stop latitude tag: "N" or "S"
207-212	PLONOF	P6. 2	Filter exposure stop longitude (deg)
213	FLOOR	A1	Filter exposure stop longitude tag: "E" or "W"
214-219	PHTMOP	P6. 0	Filter exposure stop altitude (meters)
220-229	FCOMP	A1C	Filter constituent 1 (name)
230-234	PCUMP	A1C	Filter constituent 2 "

Table A-I Continued

Bytes	Fortran Name	Fortran Format	Parameter Description, Units, and Comments
240-243	PCOMP3	I0	Filter constituent 3 "
250-259	FCOMP4	I0	Filter constituent 4 "
260-269	PCOMP5	A10	Filter constituent 5 "
270-279	PDC1	F10.3	Data for constituent 1 (micrograms/H**3)
280-289	PDC2	F10.3	Data for constituent 2 (micrograms/H**3)
290-299	PDC3	F10.3	Data for constituent 3 (micrograms/H**3)
300-309	PDC4	F10.3	Data for constituent 4 (micrograms/H**3)
310-319	PDC5	F10.3	Data for constituent 5 (micrograms/H**3)
320	SBUEX	A1	SBUEX="T" if bottle enclosed this flight, otherwise SBUEX="P"
321	SDATA	A1	SDATA="T" if bottle data on tape; otherwise SDATA="P"
322-324	SBID	I3	Sample bottle unit number
325-326	STBN	I2	Bottle number
327-332	SDATON	I6	Bottle exposure start date: Mo=327-328, DA=329-330, Yr=331-332
333-336	STIMON	I4	Bottle exposure start time (GMR) : Hr=333-334, Min=335-336
337-341	SLATON	F5.2	Bottle exposure start latitude (deg)
342	SLAONT	A1	Bottle exposure start longitude tag, "N" or "S"
343-348	SLONON	F6.2	Bottle exposure start longitude (deg)
349	SLOONT	A1	Bottle exposure start longitude tag, "E" or "W"
350-355	SHTMON	F6.0	Bottle exposure start altitude (meters)
356-361	SDATOF	I6	Bottle exposure stop date: Mo=356-357, DA=358-359, Yr=360-361
362-365	STIMOF	I4	Bottle exposure stop time (GMR) : Hr=362-363, Min=364-365
366-370	SLATOF	F5.2	Bottle exposure stop latitude (deg)
371	SLAOFF	A1	Bottle exposure stop longitude tag: "N" or "S"
372-377	SLONOF	F6.2	Bottle exposure stop longitude (deg)
378	SLOOFF	A1	Bottle exposure stop longitude tag: "E" or "W"
379-384	SHTMOF	F6.0	Bottle exposure stop altitude (meters)
385-394	SCOMP1	A10	Bottle constituent 1 (name)
395-404	SCOMP2	A10	Bottle constituent 2 "
405-414	SCOMP3	A10	Bottle constituent 3 "

Table A-1 Completed

Bytes	Fortran Name	Fortran Format	Parameter Description, Units, and Comments
415-424	SCOMP4	A10	Bottle constituent 4 "
425-434	SCOMP5	A10	Bottle constituent 5 "
435-444	SDC1	F10.1	Data for constituent 1 (PPTV)
445-454	SDC2	F10.1	Data for constituent 2 "
455-464	SDC3	F10.1	Data for constituent 3 "
465-474	SDC4	F10.1	Data for constituent 4 "
475-484	SDC5	F10.1	Data for constituent 5 "
485-489	a	P5.3	03 destruction constant (see eq. 1)
490-494	b	P5.3	03 destruction constant (see eq. 1)
495-499	c	P5.1	03 destruction constant (see eq. 1)
500-507	d	E8.2	03 destruction constant (see eq. 1)
508-512		5A1	spares

\*if ID="N", no data for this instrument this flight

Table A-II Format for DATA Records

Bytes	Fortran Name	Fortran Format	Parameter Description, Units, and Comments
1-4 5	RECID LBPLG	A4 A1	RECID= "DATA" LBFLG="L" if this is the last data record this flight; LBPLG=";" If this is the last GASP data record in the file and the following file is a GASP data file; LBPLG="T" If this is the last GASP data record in the file and the following file is a tropopause pressure file; otherwise LBFLG=" "
6-9 10 11-12	RECORD FRAME MODE	I4 I1 I2	Record number on TAPID Frame number on TAPID Program mode from DMCU MODE = 4 identifies a normal recording MODE = 10 identifies a continuous recording
13	TYPE	A1	Record type from DMCU
14	CYCLE	A1	Call set up from DMCU
15-20	DATE	I6	Mo=15-16, Da=17-18, Yr=19-2C
21-24	TIME	A4	(GMT). Hr=21-22, Min=23-24
25-30	ALTPAV	F6.0	Altitude (ft)
31-36	ALTMAR	F6.0	Altitude (meters)
37-43	PAMB	F7.2	Ambient static pressure in hectopascals (mb) - calc from ALTPAV
44	ALTAS	A1	ALTAG="C", "D", or "G" indicates climb, descent, or ground
45-49	LAT	F5.2	Latitude (deg)
50	LATAG	A1	Latitude hemisphere, "N" or "S"
51-56	LONG	F6.2	Longitude (deg)
57	LONGTAG	A1	Longitude hemisphere, "E" or "W"
58-62	XI	F5.2	Aircraft position in NMC grid coordinates
63-67	YJ	F5.2	Aircraft position in NMC grid coordinates
68-71	HEADG	F4.0	Aircraft heading (deg)

Table A-II Continued

Bytes	Fortran Name	Fortran Format	Parameter Description, Units, and Comments
72	HEADGT	A1	Tag for HEADGT
73-76	TASK	F4.0	True airspeed (knots)
77-81	XMATAS	F5.3	Flight mach number
82	TATAG	A1	Tag for TASK and XMATAS*
83-86	WS	F4.0	Wind speed (knots)
87-90	WSM	F4.0	Wind speed (meters/sec)
91	WSTAG	A1	Tag for WS and WSM*
92-95	WDEG	F4.0	Wind direction (deg)
96	WDEGTG	A1	Tag for WDEG*
97-100	SAT	F4.0	Static (ambient) air temperature (deg C)
101	SATAG	A1	Tag for SAT*
102-229	ACC(I)	32F4.2	Aircraft acceleration (gS); 32 values each record at 8/sec
230-233	ACCMAX	F4.2	Max of ACC(I)
234-237	ACCMIN	F4.2	Min of ACC(I)
238-239	NE	I2	Number of times ACC(I) > 1.2 or ACC(I) < -0.8
240	ACCTAG	A1	Tag for ACC(I), ACCMAX, ACCMIN, NE*
241-245	ZEN	F5.1	Solar elevation angle (deg); 0 deg = horizontal
246	SUNTAG	A1	SUNTAG="N" if sun below horizon
247-252	03	F6.0	Ozone data (PPBV)
253	03TAG	A1	Tag for 03*
254-259	03A	F6.0	Ozone data (PPBV); ave for 128 sec preceding recording
260	03ATAG	A1	Tag for 03A*
261-266	C3S	F6.0	Ozone std deviation (PPBV); for 128 sec preceding recording
267	03STAG	A1	Tag for 03S*
268-273	DFPTA	F6.1	Dew/frost point temperature (deg C)
274-279	WVMRA	F6.1	Water vapor mixing ratio (PPMV)
280	DPTAGA	A1	Tag for DFPTA and WVMRA; if DFPTA=SAT, DFTAGA="S"*
281-286	COAVG	F6.1	Carbon monoxide data (PPMV)
287	COTAGA	A1	Tag for COAVG*
288-293	COA	F6.3	Carbon monoxide data (PPMV); ave for 128 sec preceding recording
294	COATAG	A1	Tag for COA*

Table A-II Completed

Bytes	Portran Name	Portran Format	Parameter Description, Units, and Comments
295-300	COSD	F6.3	Carbon monoxide std deviation (PPMV); for 128 sec preceding recording
301	COSTAG	A1	Tag for COSD*
302-311	PD1	1PE10.3	Particle density for particles > D1 (particles/H**3)
312	PDTAG1	A1	Tag for PD1*
313-322	PD2	1PE10.3	Particle density for particles > D2 (particles/H**3)
323	PDTAG2	A1	Tag for PD2*
324-333	PD3	1PE10.3	Particle density for particles > D3 (particles/H**3)
334	PDTAG3	A1	Tag for PD3*
335-344	PD4	1PE10.3	Particle density for particles > D4 (particles/H**3)
345	PDTAG4	A1	Tag for PD4*
346-355	PD5	1PE10.3	Particle density for particles > D5 (particles/H**3)
356	PDTAG5	A1	Tag for PD5*
357-361	CLSEC	F5.0	Time in clouds (sec) during 255 sec preceding recording
362-365	CLAYR	F4.0	Number of cycles in and out of clouds (layers) during 255 sec preceding recording
366	CLTAG	A1	Tag for CLSEC and CLAYR; if CLSEC > 0, CLTAG="C"**
367-373	TRPRMB	F7.2	Tropopause pressure in hectopascals (mb)
374	TPTAG	A1	If TPTAG = "", TRPRMB from 12 hour interpolation If TPTAG = "L", TRPRMB from 24 hour interpolation If TPTAG = "E", TRPRMB from nearest NMC reporting period If TPTAG = "H", NMC data is not available
375-381	DEL_P	F7.2	See the report text for a complete description of TPTAG criteria
382-387	TRPRHM	F6.0	DELP = TRPRMB - PAMB, in hectopascals (mb)
388-394	DELHGT	F7.0	Tropopause height in meters (from TRPRMB assuming std. atm.)
395	GMTAG	A1	DELHGT = ALTMHV - TRPRHM, in meters Tag for TIME*
396-512		117A1	SPARES

\* If TAG="M", corresponding data field will be zero;  
the "M" tag is used whenever data are not available  
or an instrument is in a calibration mode.

Table A-III Format for TRPR Records

Bytes	Fortran Name	Fortran Format	Parameter Description, Units, and Comments
1-4	RECID	A4	RECID = "TRPR"
5	HEMIS	A1	HEMIS= "N" for Northern Hemisphere
6-11	DATE	I6	Date of Observation; Mo=8-9; Da=8-9; Yr=10-11
12-15	TIME	A4	GMT of Observation; Hr=12-13; Min=13-14
16	NBLOCK	I1	NBLOCK = Block Counter this data array
17-18	ISTART	I2	ISTART = 1 + (NBLOCK-1) * 10
19-20	ISTOP	I2	ISTOP = NBLOCK*10 for NBLOCK = 1-6; ISTOP = 65 for NBLOCK=7
21-22	JSTART	I2	JSTART = 1
23-24	JSTOP	I2	JSTOP = 65
25-30	SCALE	E6.1	Scale factor for TROP(I,J)
31-43	A	E13.6	Base for TROP(I,J)
44-100	ELE(I,J)	57I1 65C16	Tropopause Pressures in hectopascals (mb), TROP(I,J)=ELE(I,J)*SCALE+A where: ((ELE(I,J),I = ISTART,ISTOP),J = JSTART,JSTOP) Note that in the seventh block of each array only bytes 101-205 are needed.
4001-4096		96I1	Spares

## APPENDIX B - LATITUDE AND LONGITUDE FROM NMC COORDINATES

The tropopause pressure data included on GASP tapes are given at each of the 4225 points on the NMC 65 X 65 grid, a square matrix transformed from a polar stereographic map of the Northern Hemisphere. In the NMC coordinates the North Pole is the point (33,33), with the 10 deg E - 170 deg W meridian given by the line YJ = 33, and the 100 deg E - 80 deg W meridian given by the line XI = 33. The transformation from this coordinate system to latitude (deg N or S) and longitude (deg E or W) is as follows:

$$\text{Let } R = \sqrt{(XI-33)^2 + (YJ-33)^2} / \text{RHO} \quad (\text{A1})$$

where RHO = 31.2043

The Latitude (deg) is given by

$$\text{THETA} = (180/\text{PI}) \arcsin((1-R^2)/(1+R^2)) \quad (\text{A2})$$

If THETA > 0, LAT = THETA and LATAG = "N"

If THETA < 0, LAT = -THETA and LATAG = "S"

The Longitude (deg) is given by

$$\text{PHI} = -(10 + (180/\text{PI}) \arctan((YJ-33)/(XI-33))) \quad (\text{A3})$$

If  $-190 < \text{PHI} < -180$ , LONG = PHI + 360 and LONGTAG = "W"

If  $-180 < \text{PHI} < 0$ , LONG = -PHI and LONGTAG = "E"

If  $0 < \text{PHI} < 170$ , LONG = PHI and LONGTAG = "W"